CAPACITORS WITH RECESSED RIVETS ALLOW SMALLER IMPLANTABLE DEFIBRILLATORS

Cross-Reference to Related Application(s)

This patent application is a division of U.S. Patent Application No. 09/607,382, filed on June 30, 2000, which is a continuation of U.S. Patent Application No. 09/465,095, filed on December 16, 1999, now abandoned, the specifications of which are incorporated herein by reference.

Background of the Invention

The present invention concerns capacitors, particularly those for use in medical devices, such as implantable defibrillators.

Every year more than half a million people in the United States suffer from heart attacks, more precisely cardiac arrests. Many of these cardiac arrests stem from the heart chaotically twitching, or fibrillating, and thus failing to rhythmically expand and contract as necessary to pump blood. Fibrillation can cause complete loss of cardiac function and death within minutes. To restore normal heart contraction and expansion, paramedics and other medical workers use a device, called a defibrillator, to electrically shock a fibrillating heart.

Since the early 1980s, thousands of patients prone to fibrillation episodes have had miniature defibrillators implanted in their bodies, typically in the left breast region above the heart. These implantable defibrillators detect onset of fibrillation and automatically shock the heart, restoring normal heart function without human intervention. The typical implantable defibrillator includes a set of electrical leads, which extend from a sealed housing into the heart of a patient after implantation. Within the housing are a battery for supplying power, heart-monitoring circuitry for detecting fibrillation, and a capacitor for storing and delivering a burst of electric charge through the leads to the heart.

The capacitor is typically an aluminum electrolytic capacitor. This type of capacitor usually includes stacked strips of aluminum foil and paper rolled up to form a cylindrical structure called an active element. The active element is typically placed in a round tubular can which is sealed shut with a flat circular lid, known as a header. (The header usually consists of two thin bonded layers, one rubber and the other phenolic resin.) Extending from the header are two terminals connected to the rolled up foils in the active element. The terminals are usually fastened to the lid using two rivets.

Each rivet has a short shank, or rod, with a broad head on one end. (The rivet head, typically round like the head of a nail, has a diameter of about four millimeters (three sixteenths of an inch) and a thickness of about one millimeter.) The shank extends through holes in the terminal and the header, with the head resting against the interior side of the header and its opposite end extending from the exterior side. The opposite end is flattened or otherwise deformed to prevent the shank from passing back through its hole, thereby fastening the terminal to the header.

In recent years, manufacturers of electrolytic capacitors have focused almost single-mindedly on improving the active element by developing aluminum foils, electrolytes, and multiple-anode arrangements that improve capacitor performance, specifically energy density ---the amount of energy or charge a capacitor stores per unit volume. For example, because energy density is directly proportional to the surface area of the aluminum foil making up the active element, manufacturers have developed methods of etching microscopic hills and valleys into foil to increase its effective surface area.

In comparison, capacitor manufacturers have made little or no effort to reduce the size of capacitors through space-saving assembly techniques. For example, the inventors determined that the conventional use of rivets to fasten terminals to the capacitor lid, or header, wastes space. Specifically, they determined

that conventional capacitor manufacturers generally increase capacitor height (or reduce foil dimensions) to accommodate the heads of the rivets that fasten terminals to headers. The rivet heads are electrically conductive and must be prevented from touching, or contacting, the foils in the active element. So, capacitor manufacturers increase the height of the case to provide clearance between the rivet heads and the foils. Unfortunately, this increases not only the size of the capacitors, but also the size of devices, such as implantable defibrillators, that incorporate them.

Accordingly, the inventors identified an unmet need to reduce the size of electrolytic capacitors, especially those intended for implantable defibrillators, through better techniques and structures for fastening terminals to capacitor headers.

Summary of the Invention

To address this and other needs, the inventors devised a capacitor having a header which includes one or more recesses. The recess receives the head of a rivet or other fastener and thus reduces or eliminates the need to increase capacitor height or reduce foil dimensions to achieve clearance between the fasteners and other capacitor parts, such as active-element foils. More particularly, the exemplary embodiment includes a header having two recesses, each with a depth that allows the head of a rivet to be substantially flush, or coplanar, with the underside of the header. In another embodiment, the header has a single recess to receive two rivet heads.

In devising this improvement, the inventors departed from at least two conventional capacitor design objectives: reducing the number of assembly steps per capacitor and reducing manufacturing waste or cost. Conventional capacitor manufacturers make hundreds of thousands or even millions of capacitors every year and are thus continually seeking ways to reduce capacitor assembly time. Indeed, saving (that is, omitting or skipping) even one manufacturing step amounts to considerable time and cost savings when multiplied by hundreds of thousands or

millions of capacitors. Conversely, adding a step, such as forming one or more recesses in a header, to the manufacture of each capacitor generally increases assembly time and cost.

Similarly, conventional capacitor manufacturers who make thousands or millions of capacitors may also be concerned about reducing material waste, particularly seeking and developing capacitor designs and assembly practices which minimize or reduce the risk of destroying an entire capacitor or capacitor part during manufacture. Indeed, designs and manufacturing steps which pose a high risk of destroying an entire capacitor or capacitor part, such as a header, are generally avoided. Conventional headers are only about 2.5 millimeters thick and comprise two bonded layers of material. Forming one or more recesses in this type header not only adds a step to the manufacturing process, but also presents a risk of destroying it and thus increasing manufacturing waste and cost.

Brief Description of the Drawings

Figure 1 is a perspective view of an exemplary cylindrical electrolytic capacitor 10 embodying the present invention.

Figure 2 is a cross-sectional view of capacitor 10 in Figure 1 taken along line 2-2 to show internal details of the capacitor, including an exemplary header assembly 14 having a recess 14c which receives a rivet head 17a.

Figure 3 is a top perspective view of a header assembly 14 which comprises a recess 16 for the heads of rivets 15a and 17a.

Figure 4 is a bottom perspective view of header assembly 14, showing rivet heads 15b and 17b within a recess 14c.

Figure 5 is a perspective view of an alternative embodiment of header assembly 14, which provides two recesses 14c for rivet heads 15b and 17b.

Figure 6 is a block diagram of an implantable defibrillator 30 which includes one or more electrolytic capacitors 36a in accord with the invention.

Description of the Preferred Embodiments

The following detailed description, which references and incorporates Figures 1-6, describes and illustrates one or more specific embodiments of the invention. These embodiments, offered not to limit but only to exemplify and teach, are shown and described in sufficient detail to enable those skilled in the art to implement or practice the invention. Thus, where appropriate to avoid obscuring the invention, the description may omit certain information known to those of skill in the art.

Figure 1 shows a perspective view of an exemplary electrolytic capacitor 10 which incorporates a space-saving header assembly according to the present invention. Capacitor 10, which has a height 10h and a diameter 10d, includes a cylindrical aluminum case, a header (or lid) assembly 14, and two electrically conductive terminals 16 and 18. (Height 10h is measured along a longitudinal axis.) Two aluminum rivets 15 and 17 respectively fasten terminals 16 and 18, which for example comprise solid aluminum or steel with a solder plate, to header assembly 14. Rivets 15 and 17 include respective upper heads 15a and 17a, and respective lower heads 15b and 17b, which are joined via respective intermediate rods, or shanks, 15c and 17c. (Lower heads 15b and 17b and shank 15c and 17c are visible in this perspective view. With the exception of shank 15c, which is not visible in any of the Figures, shank 17c and heads 15b and 17b are shown respectively in Figure 2 and in Figures 4 and 5.) Other embodiments of the invention substitute other types of fasteners, for example, screws or bolts, for rivet 15 or 17. Thus, the present invention is not limited to any particular fastener.

Aluminum case 12 includes a circumferential seating groove 12a and a rolled lip 12b which secure header assembly 14 within an otherwise open end of case 12.

(In this exemplary embodiment, an aluminum plate fused or formed integrally with case 12 closes the opposite end, or bottom of case 12. However, in other embodiments it could be advantageous to close the bottom end with a second header assembly.) Seating groove 12a has an exemplary radius of about 0.035 inches. Lip 12b, which can be formed by rolling over the top edge of case 12, has an exemplary radius of about 0.015 inches. Figure 2 also shows that seating groove 12a is a distance 12d, for example 0.145 inches, from rolled lip 12b.

Figure 2, a cross-section taken along line 2-2 in Figure 1, generally shows that case 12, which has a thickness 12t, houses an active element 20. Active element 20 conventionally comprises a rolled assembly of an anode foil, a cathode foil, and at least one insulative separator, with each foil connected respectively to one of lower rivet heads 15b and 17b via an aluminum foil tab, such as tab 25. Lower rivet heads 15b and 17b, in the exemplary embodiment, are ultrasonically welded to a respective aluminum foil tab, with the ultrasonics applied in a shear direction relative the tab and the rivet head. An exemplary technique uses a 40 Megahertz Ultrasonic Welder from Amtech Corporation with the following operating criteria:

Energy:	11-18 Joules
Clamp Force:	13-18 pounds per square inch
Pressure:	18-28 pounds per square inch
Amplitude:	11-12 micrometers
Time Limit:	0.15 - 0.50 seconds
Power:	55-110 watts.

However, other embodiments use different welders with different operating criteria.

Figure 2 also shows that header assembly 14 comprises two bonded layers 14a and 14b, which provide a total header thickness 14t between upper and lower planar surfaces 14u and 14l. In the exemplary embodiment, header thickness 14t is about 2.5 millimeters, with layers 14a and 14b each being about 1.25 millimeters

thick. Layer 14a consists of rubber and layer 14b consists of a phenolic resin. However, in other embodiments, header assembly 14 comprises three or more layers with a lesser or greater total thickness or one layer with an equal, lesser, or greater total thickness. Additionally, other embodiments form header assembly 14 from other materials: for example, thermoplastics, epoxies, and inert polymers using suitable molding technologies. Thus, header assembly 14 is not limited to any particular layered structure, dimensional selection, or composition.

Header assembly 14 also includes at least one recess 14c, which has a recess depth 14d less than the thickness of layer 14b in the exemplary embodiment, but more generally less than header thickness 14t. Recess 14c receives lower rivet head 17b, thereby reducing or preventing its extension below lower planar surface 14l. Recess depth 14d, in the exemplary embodiment, leaves the lower-most surface of lower rivet head 17b (or more generally fastener head 17b) lower than lower surface 14l of header assembly 14. However, in other embodiments of the invention, recess depth 14d allows the lower-most surface or portion of head 17b to be substantially flush, or coplanar, with lower surface 14l. Moreover, in yet other embodiments, recess depth 14d allows the lower-most surface or portion of head 17b to be above lower surface 14l. Thus, the invention is not limited to any particular recess depth 14d or recess profile. Likewise, the peripheral shape and size of recess 14c, though not visible in this view, are theoretically unlimited.

Figures 3, 4, and 5 are perspective views, showing further aspects of header assembly 14 not clearly evident in Figures 1 and 2. In particular, Figure 3 is a top perspective view of assembly 14, showing layers 14a and 14b, terminals 16 and 18, and upper rivet heads 15a and 17a. Figure 4, a bottom perspective view of header assembly 14 based on Figure 3, shows that layer 14b includes a single recess 14c which receives both of lower rivet heads 15b and 17b. Figure 5, another bottom perspective view of assembly 14, shows two recesses 14c: one which receives lower rivet head 15b and another which receives lower rivet head 17b. Thus, a header

assembly in accord with the present invention includes one or more recesses of any desirable shape and depth or combination of shapes and depths.

Exemplary Implantable Defibrillator

Figure 6 shows one of the many applications for space-saving electrolytic capacitor 10: a generic implantable defibrillator 30. Defibrillator 30 includes a lead system 32, which after implantation electrically contact strategic portions of a patient's heart, a monitoring circuit 34 for monitoring heart activity through one or more of the leads of lead system 32, and a therapy circuit 36 which incorporates one or more capacitors 36a similar to capacitor 10. Defibrillator 30 operates according to well known and understood principles.

In addition to implantable defibrillators and other cardiac rhythm management devices, such as pacemakers, the innovations of capacitor 10 can be incorporated into photographic flash equipment. Indeed, these innovations are pertinent to any application where small, high energy, low equivalent-series-resistance (ERS) capacitors are desirable.

Conclusion

In furtherance of the art, the inventors have devised a unique space-saving header for capacitors, particularly those for use in implantable defibrillators. In particular, the space-saving header includes at least one recess for mounting the head of a rivet flush (or more nearly flush) with the undersurface of the header, thereby allowing reduction in the height or volume of the capacitor and/or increases in the dimensions of other components, such as aluminum foils.

The embodiments described above are intended only to illustrate and teach one or more ways of practicing or implementing the present invention, not to restrict its breadth or scope. The actual scope of the invention, which embraces all ways of

practicing or implementing the teachings of the invention, is defined only by the following claims and their equivalents.